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Sustaining Sherman Island: A Water Management and Agricultural Diversification System

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ABSTRACT

The Sacramento-San Joaquin River Delta is the main water resource for California's urban and agricultural development. Sherman Island sits on the western edge of Delta system and is one of the key geographic features in balancing the flux of saltwater into the Delta. Flooding, saltwater intrusion, and ongoing subsidence are current threats to Sherman Island. The integration of components of aquaculture, hydroponics, and a levee enclosed flood storage area create a system that can actively protect against flooding disasters by reversing subsidence and stabilizing levees, has the ability to sequester carbon and restore habits, and the capacity to produce economic yields. The environmental, technical, and economic attributes of the system are examined through failure simulations, economic analysis, and environment discussion to determine if the proposed system is a feasible, sustainable and profitable solution for Sherman Island and the Delta.

INTRODUCTION

Deltas are the pinnacles of life: they provide resources for a diverse array species and it is therefore critical that we protect them. After describing the current issues facing the Sacramento San Joaquin River Delta, CA, US, this report will describe a case study of a water management and agricultural diversification system at Sherman Island which can serve as a demonstration project for future application to deltas around the globe.

The magnitude and diversity of California's agricultural, environmental, industrial, recreational, and urban interests in the Sacramento-San Joaquin Delta emphasize the importance of protecting the Delta infrastructure. Protected by 1,100 miles of levees are over 538,000 acres of farming, 64,000 acres of cities and towns, and 75,000 acres of undeveloped land from flooding and saltwater intrusion the Delta is home to nearly 515,000 people living in seven counties, 500 different plant and animal species, including 20 that are endangered and major transportation and utility infrastructure. (Department of Water Resources 2008) The Sacramento, San Joaquin, Mokelumne, Cosumnes, Calaveras Rivers and their tributaries flow into the Delta and provide water to over 22 million Californians – over two-thirds of the population.

Sherman Island sits on the western edge of the Sacramento-San Joaquin River Delta and is one of the

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key geographic features protecting the Delta as a water resource. The island is located northeast of the city of Antioch, California, and lies within the jurisdiction of Sacramento County. The Sacramento and San Joaquin rivers meet at its western boundary, which is bordered to the northeast by Three-Mile Slough. Levee instability caused by continued subsidence in the region is a severe risk to cause catastrophic failure.

If Sherman Island's levees were to fail water quality for the entire Delta and most of California, would be compromised, most likely on a timescale of years to decades. Because residents rely on the Delta for their drinking water numerous health issues would result from the Delta being compromised. In addition, the livelihoods of those who utilize the freshwater, such as farmers and industry works, could deteriorate. Delta Bearier Engineering estimates the cost to recover lost water supply and to repair levees, infrastructure, and damaged homes in the event of levee failures to be as high as $2.2 trillion (Delta Bearier Engineering 2009). The increased salinity due to saltwater intrusion will also likely destroy populations of wildlife species. The loss of species has the ladder effect on the diet and shelter of other species; thus, whole ecosystems are susceptible to deterioration.

Methods and Materials

Climate Change Considerations

Global climate change is a daunting but undeniable reality, the impacts of which must be considered. Engineered systems must be designed with these effects in mind if they are to remain resilient over the entire life span of the project. In considering just how climate change will affect the Sacramento-San Joaquin Delta, it is important to evaluate the following:

Sea-Level Rise

Numerous scenarios and global climate models (GCMs) have been developed to predict the effect of climate change on global mean sea level (GMSL). The Intergovernmental Panel on Climate Change (IPCC) gives an estimated increase in GMSL of 0.1 m - 0.9 m between the year 1990 and 2100 (DRMS, 2008). Similarly, a more recent study suggests sea level will rise by as much as 0.5 m to 1.4 m over the course of the next century (DBE, 2009).

There are several implications for Sherman Island and the Delta given these predictions. Governed by significant tidal inflows, the Delta is very susceptible to increased salinity in inland waterways due to rising sea level (DRMS, 2008). This poses a great threat to the viability of Sherman Island and the Delta as a water resource for the State of California. Saltwater intrusion into the lower Delta could compromise water quality, resulting in reduced agricultural yields and greater stresses on alternative water sources. Additionally, a higher mean sea level also means increased pressure on the already fragile levee system. Levee heights would need to be drastically increased, or else the combination of increased sea level and major storm events would pose an even greater risk to the system.

While sea level rise has greater impact on long-term water level variations, it is changes in river flow that have the biggest effect on a short-timescale for the Delta (DRMS, 2008). Most predictions indicate that there will be increased flows during the winter months and reduced flows in spring and summer. From a water resource perspective, this implies that less water will be available as the state approaches times of warmer temperature and increasing agricultural demand. Furthermore, reduced spring flows will invite saltwater intrusion further inland into the Delta at a time when even less water will be available to flush the system and maintain the integrity of water supplies.

While it is difficult to apply global climate change models to smaller scale regions such as the Delta, it can be inferred from the available studies that wind velocity and intensity will increase in the area. The serious implications of this matter are that wind velocities in the Delta region determine wind and wave action, two factors which have a significant impact on levee erosion (DRMS, 2008). Consequently, levees weakened by wind and waves are subject to greater risk of failure in the event of high water or severe storm.

Changes in average temperature and the amount and type of precipitation are also expected as part of global climate change. The amount and timing of annual runoff is one of the biggest impacts, as precipitation normally falling in the form of snow will turn to rain, reducing the amount of water available for spring flows from snow melt (CA CCC, 2009). Increased temperature will have significant effect on the temperature gradient between the San Francisco Bay Area and the Central Valley, further increasing the intensity of wind velocities (DRMS, 2008). Warmer temperatures will also lead to earlier melting of snow, resulting in reduced water availability for an agriculture-dependent state already plagued by drought.

System Overview

Any proposed system for Sherman Island and any Delta system must consider the needs of global climate change including: flood control, agricultural development, water quality, and environmental sustainability. Consequently, efforts must be made to reverse subsidence, stabilize the fragile levee system, increase economic productivity, and protect vital water and environmental resources.

The Aquaponics Water Management System combines hydroponics (soil-less agriculture), aquaculture (concentrated production of aquatic species), and restored wetlands enclosed in flood storage zone. The aquaponics system is a bio-integrated system in which waste byproducts from aquaculture are used as nutrients for plant growth in the hydroponics components. Each aquaponics system consists of fish rearing tanks, solids settling and removal tanks, a bio-filter, the hydroponics rafts and a sump. The first step of the aquaponics cycle is fish eat food and excrete ammonia rich effluent. The effluent is sent through the settling tanks to reduce the amount of suspended organic matter. Next the ammonia is removed and bacteria convert ammonia and nitrites to nitrates in the bio-filter. The nitrate rich water is then pumped to the hydroponics component where plants' roots hang into the pipes and absorb the nutrients from the water. Once water has reached the end of the hydroponics component, it is collected in a sump and then returned back to the rearing tanks. (Rakocy 2006) The water flow through the aquaculture and hydroponics systems is shown in Figure 1.

The aquaculture components sit outside of the flood management zone while the hydroponics and wetland systems dwell within. The flood storage zone spans 800 acres and is able to store 12,000 to 16,000 acre-feet of water. Figure 2 displays the approximate layout of the system which consists of floating hydroponics rafts that can move up and down with the variations of the water levels but are anchored to prevent lateral movement. In addition, the flood storage zone provides wetland acreage for wildlife habitat restoration, recreation, carbon sequestration, and subsidence reversal. Levees and Siphons function to enclose the flood storage zone, transport and store water during high river water levels as shown in Figure 3.

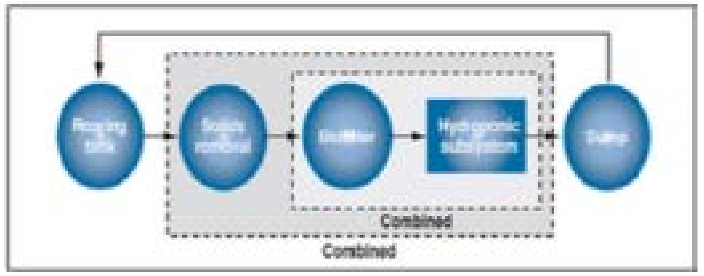


Figure 1. Water circulation through Aquaponics System (Rakocy 2006).

Figure 2. Water management system layout.

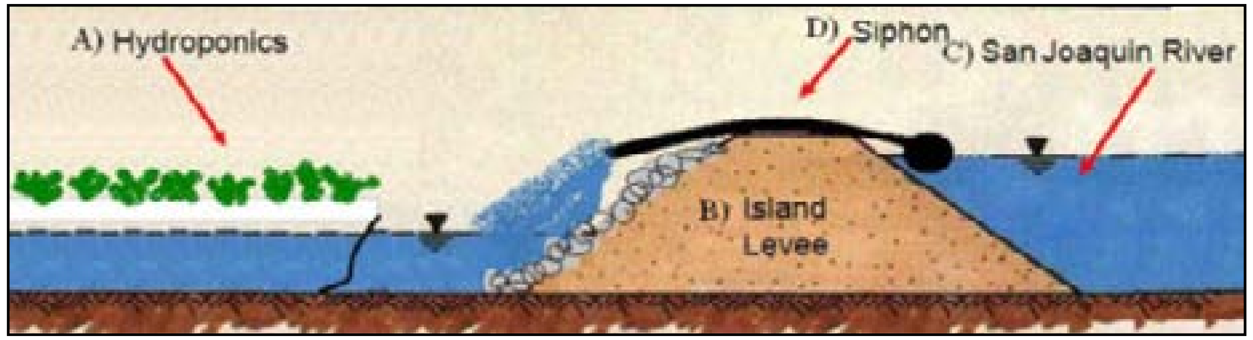


Figure 3. Flood management zone during high water event.

Infrastructure

Levees construction and upgrades are the primary infrastructure needed for the flood storage zone. Levees currently bound the northern, southern, and western edges of the Aquaponics Water Management System. The western and southern edges are bounded by Army Corp Levees protecting the Island from Sacramento and San Joaquin rivers, respectively. The northern edge is bounded by Mayberry Slough levees which are not engineered project levees. Therefore, there is little boring data and high uncertainty of the construction materials and stability. Therefore, a sandy berm will be constructed to filter, and buttress the levees to provide support. (Seed 2010c) The largest infrastructure component to construct is the internal cutoff levee to enclose the flood storage zone by bounding the eastern side. This levee will be constructed 1,160 ft west of the Antioch Bridge, encompassing Scour Lake while maintaining a buffer zone between the system and the maintenance setbacks for the Antioch bridge. Spanning approximately 3,460 ft, this levee will be made of compacted clay fill with a unit weight of 110 pcf, and cohesion of 1000 psf. The levee will have a slope of approximately 3H to 1V, a crown width of 16', and a height of 1.5' above the 100-year flood freeboad elevation. (Hanson 2009) While backside erosion may be a concern, it will be too costly to provide the entire internal perimeter with installed rip rap. Rather, to account for backside erosion, rip rap will be stocked piled on site so that it is readily available for the emergency armoring of the internal portion of the levee. Also, to allow for visual monitoring and ensure adequate maintenance vegetation must be continually removed along the toes of the levees.

Hydroponics

The Hydroponics component of the proposed system is a synthesis of Nutrient Film Technique and Deep Water Raft Hydroponics to address the needs of the Aquaponics Water Management System. Component design ratios are based on the reliable and robust University of Virgin Island's 1/8 acre system which has been in operation since the 1980's and is a model system for commercial aquaponics around globe. Hydroponics includes three main subcomponents: Nutrient Film Tubes, Buoyant Rafts, and Anchors. Nutrient Film Tubes are hollow core pipes that transport nutrients to the plant roots. They are constructed from polyvinyl chloride (PVC) and have holes eight inches apart containing net pots with growing media that supports plant roots. With 36 100-ft tubes per subsystem, each will support 5400 planters for an expected annual production of 11,000 lbs of vegetation.

Aquaponics Water Management System will be designed with 600 subsystems, so there are 3,240,000 planters in total for an approximate annual yield of six million pounds of produce. Buoyant rafts are constructed from PVC encapsulated Styrofoam, which may be recycled from Styrofoam used in packaging or other prior uses. The buoyant force per volume of Styrofoam raft is approximately 55 lbs per cubic foot. The buoyancy required to keep each subsystem afloat is approximately 35,000 to 40,000 lbs. Therefore

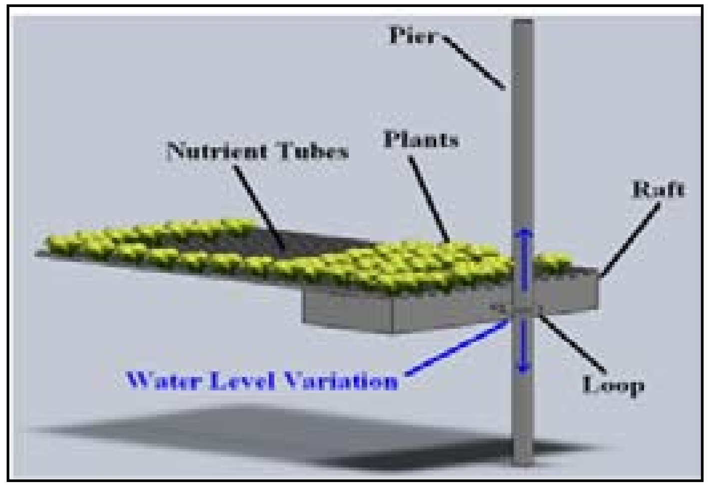


Figure 4. Schematic of anchoring system (not to scale).

Aquaponics Water Management System requires approximately 400,000 cubic ft of Styrofoam rafts to produce approximately 21 to 24 million pounds of buoyancy to keep the system afloat.

Anchors are based on a pole and slide method designed to prevent lateral movement of the rafts by wind and wave action while allowing for vertical movement of the rafts when there are changes in water height. The pole is a pier encapsulated with PVC and anchored in the ground by a concrete foundation or helix foundation anchor depending on the engineering load requirements. The loop is designed to slide vertically along the pier and is attached to the rafts as shown in Figure 4.

The advantage of hydroponics over terrestrial agriculture is that it allows for more diverse crop production. While corn, asparagus, and sugar beets were abundantly grown on Sherman Island during most of the twentieth century, the majority of crops currently grown are field crop, such as wheat and barley. (Delta Dream Team 2010) A variety of leafy vegetables, herbs, and other crops proven compatible with hydroponics can be potentially grown on Sherman Island with this system: artichokes, arugula, asparagus, basil, beets, broccoli, brussels sprouts, cabbage, carrots, cauliflower, celery, cilantro, collard, eggplant, endive, garlic, lavender, leek, lettuce leaf, okra, onions, parsley, parsnips, peas, bell peppers, radishes, raspberries, spinach, strawberries, and tomatoes. (Rakocy 2006; Hydroponics-at-Home 2010) Floriculture is also compatible with hydroponics. Combinations of these candidates would be used in order to take advantage of seasonal cycles, though some of these crops grow continuously throughout the year. Because the area does not experience extreme temperatures and frost, biennials and perennials could survive in the outdoor environment of the system. This system provides a competitive opportunity to produce crops that are unique to the area, specific to a niche market, and possibly organic. Such crops would be attractive to sell at farmers' market and local restaurants. However, additional research needs to be done to test which crops would be successful at growing on site, especially with regards to the effects of seasonal weather, water salinity, bird migration, insect plagues, and other factors that may cause crops to fail.

Aquaculture

While the equipment and resources for Aquaculture greatly depends on the fish species, a general design will be described. Incubation jars and tanks of varying sizes are needed to raise the fish. (Logan 1995) Stocking density depends on the fish size and stage of life and affects the number of tanks needed. Tanks should have water control values. Aerators and pumps are needed to provide oxygen and circulation. For fish health, filters are needed to regulate particulate concentrations in the water to the fish tanks, although not many would be needed by having snails in the tanks for cleaning. (Lindberg 2010) Feed may be live or dry, with the latter able to be delivered by automation. Depending on the temperature control needed, heaters or chillers may be necessary. A barn-like structure is necessary to house incubation and larvae tanks while adult fish tanks can be kept outdoors. Adequate piping and electrical wiring is needed among tanks, filters, and controllers. Parameters of concern to monitor are water pH, total ammonia nitrogen concentration, salinity, water temperature, and dissolved oxygen concentration. These parameters can be monitored by sensors and controlled by filters, heaters or chillers, and aerators. Each of the 600 aquaculture subsystems is comprised of 8,240 gallons of rearing tanks, 400 gallons of filtering and degassing tanks, 2,000 gallons of clarifiers, 50 gallons of base addition tanks, and 200 gallons of sump. (Rakocy 2006)

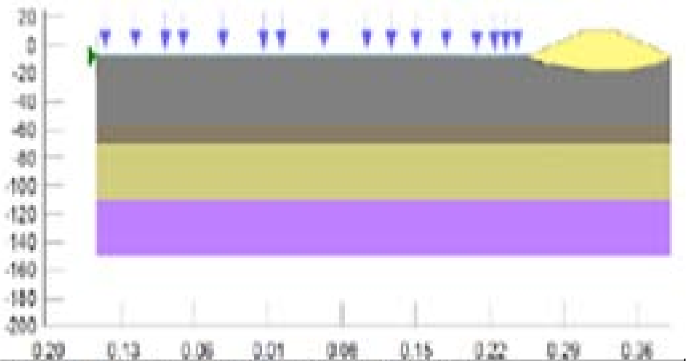
The Aquaculture system has the potential to produce fish species for several purposes including conservation, fishing or live market sale. At first, conservation of the Delta Smelt or other endangered species was considered, but this prospect was discouraged after speaking with Dr. Joan Lindberg, director of the Fish Conservation and Culture Lab, who explained that Delta Smelt aquaculture is greatly resource-intensive and not economically viable for the proposed location because the California Department of Water Resources (DWR) is planning other fish conservation efforts in Rio Vista. (Lindberg 2010) Therefore, fish rearing of species popular for fishers or sale on the live market would be more feasible for Aquaponics Water Management System. Expert opinions agree that sturgeon or catfish are good candidates for this system to produce net profit on the live market. (Doroshov 2010; Lindberg 2010; Piedrahita 2010) In addition, these species are currently fished in the Delta. (California Delta Chambers 2007) Numerous literatures on the sturgeon and catfish aquaculture allows for detailed design and protocol to be easily made. Because catfish aquaculture is predominantly in the Southeast of the United States and sturgeon aquaculture research has been completed at U.C. Davis, this report will focus on sturgeon. Sturgeon aquaculture is especially lucrative for its caviar production. (Logan 1995) While it takes almost nine years for female sturgeon to be mature with eggs, younger sturgeon is valuable for its meat. At about 18 months of age, sturgeon is profitable to sell on the live market. Raising some fish from this age to 36 months allows for sex determination, and females may be further raised for caviar production while males sold for meat. With the 600 subsystems, there is enough capacity for fifteen broodstock and their offspring. This is expected to yield 215,000 fish for sale at 18 months. Since sturgeon is already present in the Delta, unintentional release into the San Joaquin River would not jeopardize the Delta's fragile ecosystems.

RESULTS

Technical Feasibility of Design of Constructed Internal Levee

The internal cutoff levee encloses the flood storage zone and will serve as a secondary defense should river levees fail. In doing so, it must be able to withstand the principal causes of levee failure: overtopping, surface erosion, internal erosion (piping), and slides within the levee embankment or the foundation soil. (USACE 2000) Any levee constructed on Sherman Island inherits a number of issues that require intensive design, first and foremost being the quality of the foundation soils. The generalized subsurface soil profile and proposed internal levee when the internal area is back flooded to a level of 3ft (-5 ft MSL) is shown below in Figure 5. Most concerning is the approximately 40 foot peat layer that immediately underlies the levee. As a result, the foundation soils are extremely weak and compressible, variable, and feature severe underseepage vulnerability, which if left unaddressed can lead to piping and levee failure. The most common method of stabilizing is excavation and replacement of the peat layer however this is not economically feasible because the peat layer is too large. In addition to the problems with the peat layer there is a deep sand layer that has the potential to liquefy during a seismic event.

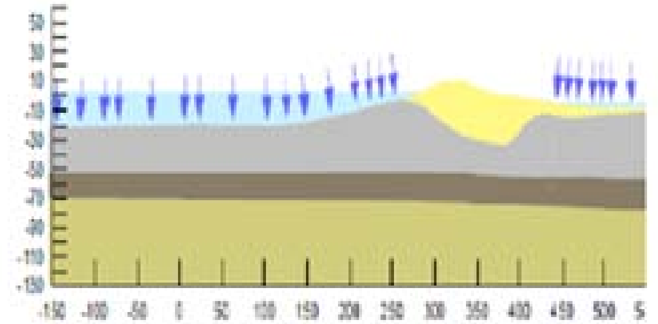
US Army Corp of Engineers standards dictate that levees should be designed to a factor of safety of 1.3 to 1.4, dependent on the time scale for which a levee will be holding back elevated levels of water. Table 1 shows the minimum factors of safety for levee slope stability



Materials (Top to Bottom)	Unit Weight (pcf)	Cohesion (psf)	Phi
Compacted Clay Fill	110	1000	0
Peat	80	0	28
Clay	90	0	0
Deep Sand	110	0	32
Deep Silt	110	1500	0

Figure 5. Soil Profile of Internal Levee with Flooded Internal Area, derived from Soil Borings 6 and 7 and CPTs 23-25.

as designated by the USACE. While the internal levee will not be kept at a high flood level indefinitely, the levee must maintain at least a factor of safety of 1.4 as it is the critical piece of infrastructure protecting the aquaculture system and the rest of Sherman Island. Modeling of our proposed clay fill levee will determine the optimum back flooding to maintain this factor of safety while equalizing the pore pressure as much as possible.



Materials (Top to Bottom)	Unit Weight (pcf)	Cohesion (psf)	Phi
SM-ML Fill	83	0	33
Peat	44	0	28
CL – ML	73	550	0
Deep Sand	97	97	36

Figure 6. Soil Profile of Existing Levee (Harvey 2010).

During design and construction of this levee, the consolidation of the peat soil needs to be considered. Until the peat layer has been compressed, there will be minimal structural stability to the levee. Since, as described by Dr. Seed (2010b), for approximately every foot of fill placed the peat will settle approximately a foot. As such, the levee will need to be constructed in stages with a first layer being installed and then allowed to settle. To allow for sufficient consolidation, this layer will remain for approximately a year and a half. At this stage the second layer can be added up to

	Applicable Stability Conditions and Required Factors of Safety			
Type of Slope	End-of-Construction	Long-Term (Steady Seepage)	Rapid Drawdown [a]	Earthquake[b]
New Levees	1.3	1.4	1.0 to 1.2	(see below)
Existing Levees	--	1.4[c]	1.0 to 1.2	(see below)
Other Embankments and dikes[d]	1.3[e,f]	1.4[c,f]	1.0 to 1.2[f]	(see below)

[a] Sudden drawdown analyses. F. S. = 1.0 applies to pool levels prior to drawdown for conditions where these water levels are unlikely to persist for long periods preceding drawdown. F. S. = 1.2 applies to pool level, likely to persist for long periods prior to drawdown.
[b] See ER 1110-2-1806 for guidance. An EM for seismic stability analysis is under preparation.
[c] For existing slopes where either sliding or large deformation have occurred previously and back analyses have been performed to establish design shear strengths lower factors of safety may be used. In such cases probabilistic analyses may be useful in supporting the use of lower factors of safety for design.
[d] Includes slopes which are part of cofferdams, retention dikes, stockpiles, navigation channels, breakwater, river banks, and excavation slopes.
[e] Temporary excavated slopes are sometimes designed for only short-term stability with the knowledge that long-term stability is not adequate. In such cases higher factors of safety may be required for end-of-construction to ensure stability during the time the excavation is to remain open. Special care is required in design of temporary slopes, which do not have adequate stability for the long-term (steady seepage) condition.
[f] Lower factors of safety may be appropriate when the consequences of failure in terms of safety, environmental damage and economic losses are small.

Table 1. Minimum Factors of Safety – Levee Slope Stability (USACE 2000).

the specifications of the levee design. The levee will be constructed with compacted clay fill with a unit weight of 110 pcf and cohesion of 1000 psf, to best limit flow through the levee.

Existing Levees

The existing levees that surround Sherman Island feature clearly delineated layers of soil similar to that in the internal portion of the island. Under seepage is a significant issue for these levees with the most common failure concern being piping. Additionally, the levees are constructed of sand rather than low hydraulic conductivity clays. Settlement through the years has led to constant repairs, and as such an irregular levee shape. Figure 6 displays the soil and levee profile that will be used for the geotechnical analysis. This levee is extremely susceptible to failure in high flood water events due to the high head differential between the rivers and subsided land inside Sherman Island. Therefore back flooding the flood storage zone is a favorable approach because it reduces the difference in hydraulic gradient.

Geostudio Simulations

To determine the effects of back flooding, on the existing levees and the constructed levee, seepage analyses and slope stability analyses parented from the seepage analyses were performed. For the proposed internal levee, the profile was generated from soil borings and CPT tests provided by Caltrans for the Antioch Bridge. The profile for the existing levee was created for the RESIN project and given to us for use by Anna Harvey. This profile is appropriate for the project site as this profile was taken from an area near a previous failure, and has an extremely large peat layer. If the flood management can benefit this failure prone levee, then it can aid in the protection of levees at the southwest site.

It should be noted that the actual 100 year and 50 year flood levels are +7.5 ft MSL and +5.5 ft MSL

Back flooding level on Sherman Island Side, above MSL	Factor of Safety
Aquaponics (-5 ft)	1.724
MSL (0 ft)	1.580
2 ft	1.473
4 ft	1.451
6 ft	1.450
7 ft	1.393
8 ft	1.284

Table 2. Factors of Safety for Proposed Internal Cut-off Levee.

	Back flood level on Sherman Island Side, above MSL					
San Joaquin River Level above MSL	No back flood (-8 ft)	Aquaponic (- 5 ft)	MSL (0 ft)	2 ft	4 ft	6 ft
MSL (0 ft)	1.598	3.483	N/A	N/A	N/A	N/A
2 ft	1.383	1.864	5.092	5.379	N/A	N/A
4 ft	1.252	1.051	.------	1.632	5.391	N/A
6 ft	0.948	0.985	1.439	.------	5.121	3.691
8 ft	0.764	0.885	0.829	1.188	.-----	1.77

Table 3. Factors of Safety for Existing Levee.

respectively. However, for simplicity of the model and to account for variability such as sea level rise, +8 and +6 ft were chosen, to provide a lower end estimate of factors of safety. The slope stability analyses were run with the Spencer (1967) method, as it is most applicable to this situation and is most accurate. (Seed 2010c). Additionally, the simulations were run assuming no tension crack.

The data given in Table 2 from simulations performed demonstrate that back flooding the internal cutoff levee to a level of MSL + 6 ft maintains a factor of safety of 1.4 while MSL + 7 ft maintains a factor of safety of 1.3. Ideally, the internal levee should maintain a factor of safety of above 1.4, and as such, the maximum back flooding of the system will be will be MSL + 6 ft. Table 3 shows that for different river water levels increasing the back flood water levels results in a increase in the the factor of safety of the levees. While there are minor variations to this trend, the levee becomes more stable with increased back flooding. This result supports the theory that the hydraulic exit gradient resulting in piping and slope instability can be reduced by the Water Management System. The optimum back flooding levels from simulations of various elevated river conditions are highlighted in Table 3. Significantly higher factors of safety for the existing sections of the Sherman Island levees can be achieved with these levels of back flooding resulting in greater levee stability and lower risk of failure from river flooding.

The driving forces for levee and piping resulting in slope failure stems from high exit gradients. Piping is a consequence of differential head and differential pore pressure. As pressure builds up on one side of the levee, water is forced towards the backside of the levee and thus increases the hydraulic gradient. This increases the already high hydraulic gradient of the peat layer even further. The addition of the temporary flood storage zone allow for siphoning water to balance water levees on each side on each side of the level. Therefore the exit gradient and pore pressures are decreased leading to a significant increase of the stability of the levees. Figure 7 compares the exit gradient for an 8+MSL flood level and back flooding of 2+MSL which indicates a reduction of the exit gradient by approximately half.

Cost Estimation of Project

Site work estimates consider the construction costs of internal cutoff levee and necessary road improvements for site access. The cutoff levee requires approximately 440,000 cubic yards of fill at $15 per cubic yard, therefore the total cost of the levee is approximately $6.6 million (Seed 2010b). For project access, revitalization of a portion of the former Victory Highway is the most likely option. The approximate length of road to be improved is 0.54 miles with an estimated cost of $1.8 million per mile constructed (Pazooki,2010). This value reflects construction equivalent to a one-foot asphalt concrete layer and gives a total of approximately $972,000. An alternative route involving revitalization of a larger portion of Victor Highway stretching roughly 2.17 miles would cost $3.9 million, which is four times the cost of the first option.

The total materials cost for the aquaponics system is approximately $23 million. This includes 600 aquaponics subsystems at $30,000 to $50,000 each, with an average of approximately $38,500. The prices of hydroponics and aquaculture components, including: tanks, pumps, anchors, and rafts per subsystem. The prices are based on data from UVI Aquaponics, CropKing Hydroponics, Dock Float Supply, Dock Builders Supply and Seaflex Anchors. Labor and construction costs are not included as further design and bidding by licensed aquaponics contractors are needed.

The cost of wetland development is extremely variable depending on the scale of the project and quality of labor and materials used. According to Dr. Alexander Horne, estimates for wetland construction range from $2,000 (volunteer labor) to $75,000 (high quality labor) dollars per acre (Horne 2010). For the purposes of this project, Dr. Horne recommends a value of $25,000 per acre of wetland constructed. Therefore for 700 acres of wetland restoration there is an initial cost of approximately $17-18 million.

Operations & Maintenance

The economic analysis of sturgeon production by Logan (1995) estimates costs of operations and maintenance per aquaculture system at approximately $3,500 to $4,000. This includes cost of labor, feed, electricity, and medicine. Assuming a 25 percent increase in these costs to account for agricultural labor, this results in operating and maintenance costs between $4,000 and $5,000 per subsystem. Consequently for the 600 systems proposed there is an annual cost of approximately $2.8 million.

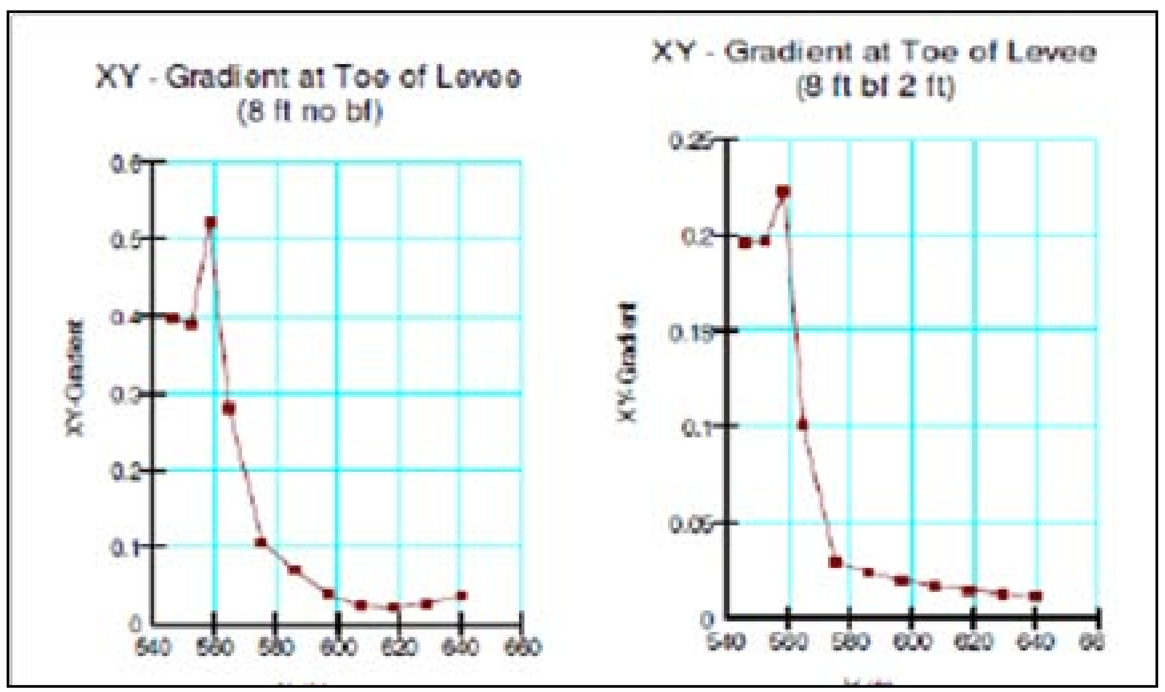


Figure 7. Exit Gradient vs. Back-flood Heights.

Revenue Estimation of Project

For the proposed system on Sherman Island, there are three chief sources of revenue. The first is the sale of agricultural yields from the hydroponics component. The second is the sale of fish yields from the aquaculture component. The third source is the economic value placed on various wetland services.

Income generated by agriculture is dependent upon the type of crop produced as well as the frequency of harvesting cycles. For the purposes of this model, it is assumed that average yield is approximately 11,000 pounds of crop per year per system. (Rakocy 2006) Price indices for crops typically used in aquaponic operations indicate that cilantro has the highest economic benefit of $88,000 per year, with onion having the lowest value of $1,100 per year. On average, each year of production will generate roughly $25,000 to $30,000 in revenue per subsystem, resulting in nearly $17 million of income over a two-year time period.

The aquaculture component of this business model uses price indices developed for similar systems rearing sturgeon. Numbers generated from previous examples include considerations for 5, 10, and 15 brood stocks. (Logan 1995) There is a harvest time of 18 months for each system, and production will likely be staggered to produce maximum output and more continuous income for the project. Considering a time period of two years, fish production gives estimated revenue of roughly $17 million assuming a sale value of $4.5 per pound of sturgeon.

Wetland value is based on a sum of averages of the following services: gas regulation, disturbance regulation, water regulation, water supply, waste treatment, habitat, food production, raw materials, recreation, and cultural ecosystem services (Costanza 1994). Revenue for these services is presented in Table 4.

Ecosystem Service	Annual Revenue ($US/ ha)
Gas Regulation	133
Disturbance Regulation	4539
Water Regulation	15
Water Supply	3800
Waste Treatment	4177
Habitat	304
Food Production	256
Raw Materials	106
Recreation	574
Cultural Service	881
Total	14785

Table 4. Wetland Revenue Breakdown (Costanza 1994)

DISCUSSION

Environmental Benefits

The wetland component of the system will provide carbon sequestration. Carbon sequestration is the capture of atmospheric CO_2 by plants such as bulrushes and cattails through photosynthesis. The Bulrush wetland can grow approximately 500 g C/ m^2 per year, half of which is preserved. The CO_2 is absorbed by the plants and then incorporated into the soil biomass as the plants decay over time. A wetland can sequester as much as 25 metric tons of CO_2 per acre per year. This helps to reduce carbon emissions while reversing subsidence (Horne 2010).

The system actively stops and reverses subsidence. By flooding the area with water the peat layer preserved because it is wet. As the plant biomass from the wetland decomposes it increase the peat layer and therefore reverses subsidence. Wetland vegetation and non-sellable crop yields from the hydroponics system can be used to restore peat. Similar subsidence reversal projects have been proposed and approve on and around Sherman Island. One such project includes Twitchell Island Ponds where an increase of 1.6 inches/year in addition to preventing subsidence of approximately 1 inch/year has been demonstrated. During flooding even there will be sediment will be transported into the system and then settle out before the water in release back into river. Therefore sediment can slowly build up with flooding events and also reverse subsidence (URS Blue Ribbon Task Force 2007).

In addition the wetland restores natural habitats for birds and aquatic species. The fish a reptile species that would take advantage of this wetland ecosystem include carp, crappie, striped bass, white catfish, and pond turtles. Along with hundreds of different bird species including the mallard duck, red-tailed hawk, eagle, Canadian goose, cinnamon teal, ring-necked pheasant, ruddy duck, wood duck and many more. The wetlands will serve to restore the delta wetland habitats as well as to sustain future bio-diversity of wetland species (SacramentoRiver.org 2010).

Water contamination and waste is reduced by the aquaponics system because nutrients and water are recycled back into the system through water recirculation. This separation of the system from the surrounding environment reduces water waste due to runoff and agricultural pollution when compared to terrestrial agriculture. Terrestrial agriculture requires a large amount of water, the majority of which is not absorbed by plants but leaves the land via groundwater runoff. Agricultural runoff promotes algal blooms and eutrophication, which lower the oxygen concentration dissolved in the water and leads to death of aquatic species.

Environmental Concerns and Mitigation

The potential environmental concerns of the wetland include the production of methane from biomass decomposition. While wetlands sequester carbon and hence reduce carbon dioxide, they release other GHGs, primarily methane (CH4) and nitrous oxide (N2O). The concern is that Methane has a Global warming potential (GWP) 21 times that of CO2, and N2O has a GWP 310 times that of CO2. Most of the GWP of CH4 occurs in the first twelve to fifteen years after its release, whereas the GWP of CO2 lasts decadnto the water within the system and the transport of such toxins into the surrounding environment. The soil at Sherman Island has been exposed to pesticides, fertilizers, and dredged soils for the bay which were contaminated with heavy metals. Therefore because the proposed design is to partially flood the soil the toxins could leach from the soil. (Horne 2010) In order to mitigate this possible issue a test flood plot an monitor the toxin release levels. Leach test or Barrel tests can be used to mimic the conditions and will give results that can be used to assess further needs of mitigation. Additionally, the heavy metals such as the metals off of ships including copper, zinc, and nickel can be immobilized in wet peat soils. Organic compounds will bind to peat and once the wetlands have been established the plants will also remove toxins from the water. Finally because the flood storage zone will contain a large volume of water the toxins will be diluted. There may be short term effects from pesticides so to prevent birds from being exposed to these toxins the use of bird scaring devices can be implemented until toxins diffuse. It is important to monitor the toxins before, during and after the installation of the wetland in order to understand the mitigation strategies that must be considered and implemented. Many of the environmental concerns can be monitored at demonstration sites including Mayberry Farms Subsidence Reversal and Carbon Sequestration Project and the Twitchell Island Ponds which both contain many of the same environmental considerations that will be faced in the flood storage zone.

CONCLUSION

This paper has served to advance the design and feasibility of a system synthesizing the technologies of aquaponics, wetland restoration, and water management at Sherman Island in order to provide future resilience and sustainability. Portions of the conceptual design considered include a system overview, environmental implications, economic analysis, and geotechnical investigation. While much has been done to assess the technical aspects of this project, it is crucial to weigh the results of this report whilst taking into account the human factor of the many stakeholders and policymakers involved in protecting Sherman Island and the Sacramento San Joaquin Delta.

The proposed Aquaponics Water Management System provides for the need to protect against levee instability, bolster a sagging agricultural economy, and restore fragile Delta ecosystems. It is a concept that works to improve all aspects of life on Sherman Island, from economic to environmental, while also taking into account the needs and concerns of the public, government, and industry. With further innovative design and continued desire for sustainability, it is a project that one day may be applicable to the much of the Sacramento-San Joaquin River Delta, and beyond.

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LITERATURE CITED

1. Bea, Robert. Personal Communication. 2010.
2. Birkey, S. and Infelise, R. Personal Communication. April 26, 2010.
3. California Climate Change Center. "Using Future Climate Projections to Support Water Resources Decision Making in California." April 2009.
4. California Delta Chambers (2007). "California Delta Chambers and Visitor's Bureau – A Guide to the California Delta Waterways." California Delta Chambers. http://www.californiadelta.org/fishing.htm (March 31, 2010)
5. Caltrans (2008). "Geotechnical Site Characterization Report: Antioch Bridge Seismic Retrofit Project." Antioch, CA.
6. Costonza, R. et al. "The value of the world's ecosystem services and natural capital." Nature. Volume 387, 15 May 1997.
7. Delta Bearier Engineering. "Ensuring the Security of California's Freshwater: Conceptual Design of a Saltwater Barrier System at Sherman Island." May 2009.
8. Delta Dream Team (2010). "Sustaining Sherman Island: A Water Management and Agricultural Diversification System." CE 180.
9. Doroshov, Serge. Personal Communication. April 2010.
10. Hansen, LeRoy T. "The viability of Creating Wetlands for sale of Carbon offsets" Journal of Agricultural and Resource Economics. 34(2):350 -364. 2009.
11. Hanson, J.C. (2009). "Rec. District 341, Sherman Island Five-Year Plan." A Corporation, San Francisco, CA.
12. Harvey, Anna. Personal Communication. April 2010.
13. Horne, Alexander. Personal Communication. April 9, 2010.
14. Hydroponics-at-Home (2010). "your garden hydroponics system." http://www.hydroponics-at-home.com/gardenhydroponics.html (March 29, 2010).
15. Lindberg, Joan. Personal communication. April 2, 2010.
16. Logan, S.H., Johnston, W.E. and Doroshov, S.I. (1995). "Economics of joint production of sturgeon (acipenser transmontanus Richardson) and roe for caviar." Aquaculture. 130:299-316.
17. National Heritage Institute. "Subsided Island Restoration Design in the Sacramento-San Joaquin Delta: A Solution for Levee Fragility and Water Supply Vulnerability in the Delta." February 2002.
18. Pazooki, Mohsen. Personal communication. March 29, 2010.
19. Piedrahita, Raul. Personal communication. April 2010.
20. Rakocy, J., Masser, M., and Losordo, T. (2006). "Recirculating Aquaculture Tank Production Systems: Aquaponics-Integrating Fish and Plant Production." Southern Regional Aquaculture Center, 454, 1-16.
21. Seed, Raymond. Personal Communication. 12 February, 2010.
22. Seed, Raymond. Personal Communication. 16 March, 2010.
23. Seed, Raymond. Personal Communication. 22 April, 2010.
24. Silverman, Jacobs. "Do cows pollute as much as cars?" http://animals.howstuffworks.com/mammals/methane-cow.htm, 2010.
25. Technical Memorandum: Delta Risk Management Study (DRMS) Phase 1, Topical Area: Climate Change, Prepared By: URS Corporation/Jack R. Benjamin & Associates, Inc. January 25, 2008.
26. URS Blue Ribbon Task Force. "Technical Memorandum: Delta Risk Management Study (DRMS) Phase 2." 2007.
27. US Army Corps of Engineers (2000). "Engineering and Design: Design and Construction of Levees." Manual No. 110-2-1913. Washington, DC 20314-1000. April 30, 2000.
28. US Department of Labor. "Occupational Safety and Health Administration Fact Sheet: Hydrogen Sulfide." 2005 Sacramento River. "A Guide to Recreation and Public Access: Lower Sherman Island Wildlife Area." http://sacramentoriver.org/access_site.php?access_site_id=173&q=Sherman%20Island&q_type=access_sites&serial=N%3B, 2010.